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TITLE: BOVINE POLYNUCLEOTIDE VACCINE FOR THE
INTRADERMAL ROUTE

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CLAIMS: 15 (2 independent)

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BOVINE POLYNUCLEOTIDE VACCINE FOR THE INTRADERMAL ROUTE

The present invention relates to an improvement made to the vaccination of bovines.

5 Immunization and vaccination by direct administration of nucleotide sequences encoding an immuno-
genic protein (called DNA or polynucleotide vac-
cination) has been described in Patent Application
WO-A-90 11092. The protein encoded by the inserted
10 nucleotide sequence is capable of being expressed in
the cells and of bringing about the development of an
immune response. This application envisages the use of
naked DNA as well as of DNA contained in liposomes.
Preferably, the DNA is introduced into the muscle. The
15 DNA could also be introduced into the skin, into
certain organs or into the blood, making it possible
for the injection to be carried out in different ways
such as by the intradermal route, the transcutaneous
route, the intravenous route and the like.

20 The studies which followed the first descrip-
tions of this technique have demonstrated the benefit
of using either the intramuscular route for injecting
DNA, or the so-called "gene gun" method which consists
in propelling metallic microparticles, such as gold
25 microparticles coated with DNA, directly into the
superficial cell layer of the skin.

J.B. ULMER et al., *Science*, Volume 259, 19
March 1993, 1745-1749; G.J.M. COX et al., *J. of
Virology*, Volume 67, No. 9, September 1993, 5664-5667
and Z.Q. XIANG in *Virology* 199, 132-140 (1994), have
30 described DNA vaccination trials using the intra-
muscular route.

35 It has also been widely demonstrated that the
intramuscular route gives superior results to the
intradermal route but that, in the final analysis, the
most promising route is the use of "gene gun" because,
with this technique, the administered doses are much
less than the doses required by the intramuscular
route. Reference may be made to F. FYNAN et al., in
P.N.A.S. USA Volume 90, 11478-11482, December 1993,
40 WO-A-95/20660.

Likewise, D. TANG et al., (Nature 356, 152-154, 12 March 1992) have shown the absence of immune response after the administration of human growth hormone by the intradermal route with the aid of a hypodermic needle. The authors have, on the other hand, demonstrated the obtaining of an immune response with the aid of the "gene gun" technique.

Only E. RAZ et al., (P.N.A.S. USA, Vol. 91, 9519-9523, September 1994) have reported that intradermal administration could induce high antibody titres.

For its part, the "gene gun" technique has the disadvantage of being difficult and expensive to use, since it requires the preparation and the use of gold particles coated with DNA and their administration with the aid of a special propellant.

Some authors have therefore developed an alternative technique which envisages the use of an apparatus for liquid jet administration. There may be mentioned P.A. FURTH et al. in Analytical Biochemistry 205, 365-368, 1992, who describe the use of the apparatus called Ped-o-jet, which is an injector used to deliver human vaccines into muscle tissues, for the administration of a DNA vaccine. The authors report that the injector can cause DNA to pass through the skin and reach the muscles, the fatty tissue and the mammary tissue of live animals.

H.L. VAHLSING et al., in Journal of Immunological Methods 75 (1994) 11-22, describe the use of the apparatus called Med-E-Jet for transcutaneous and intramuscular administration.

There may also be mentioned M. JENKINS et al., in Vaccine 1995, Volume 13, No. 17, 1658-1664, who describe the use of jet vaccination into the muscle.

The bovine respiratory syncytial virus BRSV is present worldwide and can cause severe diseases of the lower respiratory tract in bovines, this disease being similar to that caused by the respiratory syncytial virus HRSV in children. During one study, it was found that more than 95% of 2-year old calves were infected

with the BRSV virus (Van der Poel et al., Archives of Virology 1993, 133, 309-321).

The need for a vaccine against the BRSV virus is felt but has not given rise to the development of effective vaccines. The first attempts to vaccinate children have led to the appearance of facilitation of the disease after natural infection, suggesting that the vaccination could be dangerous (Anderson et al., Journal of Infectious Diseases, 1995, 171 : 1 to 7). It is known, however, that antibodies against the two major surface glycoproteins, F (fusion protein) and G (attachment protein) could play a role in protection (Kimman and Westenbrink, Archives of Virology, 1990, 112 : 1 to 25). Numerous studies have also been carried out on mouse-, dog- and ferret-type animal models. On the other hand, vaccination trials on bovines with the purified F protein have not given a conclusive result since, as in children vaccinated with HRSV, the calves developed neutralizing antibodies and nonneutralizing antibodies which could interfere with the immune response during a subsequent infection with the virus (L.D. Nelson et al., Am. J. Vet. Res., Vol. 53, No. 8, August 1992, p. 1315-1321).

The objective of the present invention is to provide an improvement in the vaccination of bovines with DNA, which makes it possible to ensure a vaccination which is at least as effective as vaccination by the intramuscular route or by the "gene gun" technique but which is easier and less expensive to use.

Another objective of the invention is to provide such an improvement leading to increased safety, essentially as regards the vaccination residues present in the tissues.

Another objective of the invention, which relates to the vaccination of animals intended for consumption, is also to ensure safety such that the vaccination has no unfavourable effect on the appearance of the meat.

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Another objective of the invention is to provide a means for mass vaccination.

A specific objective of the invention is to provide such a vaccine allowing the protection of bovines against the BRSV virus, the IBR virus, the BVD virus or the PI-3 virus.

The Applicants have found that it is possible to meet these objectives by administering the vaccine by the intradermal route with the aid of a liquid injector without a needle, ensuring, at 5 points, distribution of the vaccine essentially in the epidermis, the dermis and the hypodermis. The trials conducted by the Applicants in the field of vaccination of bovines against the bovine respiratory syncytial virus (Bovine Respiratory Syncytial Virus, BRSV) have made it possible to obtain superior immunization results by this route compared to that obtained by the intramuscular route.

The present invention proposes, for the first time, the vaccination of bovines with polynucleotide vaccines (or DNA vaccines or plasmid vaccines) designed for, and administered by, the intradermal route by means of a liquid jet injector without a needle.

The subject of the present invention is therefore a polynucleotide vaccine formula comprising an intradermally effective quantity of a plasmid combining a DNA sequence encoding an immunogen and a promoter allowing the expression of this immunogen in vivo in the cells of the skin, this vaccine formula being suitable for intradermal administration (the cells of the epidermis, dermis and hypodermis are targeted in particular; the administration is intended in particular to present the expressed antigens to the dendritic Langerhans' cells of the skin, which cells are localized essentially in the epidermis) with an apparatus for liquid jet intradermal administration, in particular the apparatus called Pigjet (manufactured and distributed by Endoscopic, Laons, France) or an equivalent apparatus delivering the vaccine through a

5-nozzle head under conditions equivalent to the Pigjet. In general, the vaccine formulae according to the invention are suitable for administration with an apparatus for liquid jet administration having from 1 to 10 nozzles, preferably from 4 to 6, still more preferably from 5 to 6.

10 This requires a vehicle suited to the intradermal route, such as water, buffer, physiological saline, liposomes, cationic lipids and, in general, a vehicle of low viscosity, especially equivalent or close to that of water, and a dose volume which is useful and effective by this route.

15 In particular, but not exclusively, with an apparatus having 5 or 6 nozzles, that is to say administering the dose through 5 or 6 openings and in the form of 5 or 6 jets of identical volume, the dose volume may be advantageously between 0.1 ml and 0.9 ml, preferably between 0.2 ml and 0.6 ml, preferably of the order of 0.4 to 0.5 ml.

20 The vaccine formula will comprise an intradermally effective quantity of plasmid which will be in general from 10 ng to 1 mg, preferably from 100 ng to 500 μ g, preferably from 0.5 μ g to 50 μ g of plasmid.

25 Typically, the invention seeks to administer the vaccine formula at several points so as to optimize the transfection of cells with the plasmids. This results in a preference for the use of an injection head with several holes. This can also be combined with a multi-application of the apparatus, that is to say 30 with the distribution of the vaccinal dose in more than one application of the apparatus at different sites. In a particularly preferred manner, it will be possible to use an apparatus with 5 or 6 holes in mono-application or in multi-application, preferably in double-application.

35 A typical case of the invention is a DNA sequence coding for an immunogen of the BRSV virus, and in particular for the G and/or F gene from this virus

(for example 391-2 strain: R. Lerch et al., *Virology*, 1991, 181, 118-131).

Another typical case of the invention is a DNA sequence coding for an immunogen of the infectious bovine rhinotracheitis (IBR) virus or bovine herpesvirus (BHV), in particular for the gB gene and/or the gD gene (for example ST strain : Leung-Tack P. et al., Virology, 1994, 199, 409-421).

Another typical case of the invention is a DNA sequence encoding an immunogen of the mucosal disease virus (BVD), in particular the E2 gene and/or the E1 gene (for example Osloss strain : L. De Moerlooze et al., J. Gen. Virol., 1993, 74, 1433-1438). It is also possible to combine genes from different subtypes of BVD, for example from North America and from Europe (A. Dekker et al., Veterinary Microbiol., 1995, 47, 317-329).

Yet another typical case of the invention is a
DNA sequence coding for an immunogen of the type 3
20 parainfluenza virus (PI-3), in particular for the HN
gene and/or the F gene, preferably the HN gene
(sequence of the F and HN genes which was deposited by
H. Shibuta in 1987, GeneBank sequence accession No. =
Y00115).

25 In case of a combination of 2 genes, for example F and G from BRSV, HN and F from PI-3 or gD and gB from IBR, the corresponding sequences can be inserted into the same plasmid or into different plasmids.

Pathogenic agent gene is understood to mean
30 not only the complete gene but also the various nucleo-
tide sequences, including fragments, which retain the
capacity to induce a protective response. The notion of
a gene covers the nucleotide sequences equivalent to
those described precisely in the examples, that is to
35 say the sequences which are different but which encode
the same protein. It also covers the nucleotide
sequences of other strains of the pathogen considered,
which provide cross-protection or a protection specific
for a strain or for a strain group. It also covers the

nucleotide sequences which have been modified in order to facilitate the in vivo expression by the host animal but which encode the same protein.

It is of course understood that the invention
5 consists in the adaptation of the prior art DNA vac-
cines to an intradermal administration by an apparatus
for liquid jet administration. While this results in
modifications in the vaccine formula and in particular
10 in the viscosity, the quantity of DNA and the dose vol-
ume to be administered, it goes without saying that the
invention applies, moreover, to any DNA vaccine con-
structs described in the prior art. Persons skilled in
the art will therefore be able to refer to the state of
15 the art in the DNA vaccination field and in particular
to the documents discussed above.

More specifically, the transcription units used
in the vaccine formulae according to the invention will
comprise a strong eukaryotic promoter, such as the hCMV
IE promoter.

20 The vaccine formula according to the invention
may be packaged in a multidose vial, for example of 10
to 100 doses, fitted to an apparatus for liquid jet
intradermal administration, preferably the Pigjet.

25 The subject of the present invention is also a
portable bovine vaccination unit comprising an
apparatus for liquid jet administration and a suitable
vial comprising several doses of a vaccine formula as
described above, the apparatus for administration being
30 designed so as to deliver a dose of vaccine formula
intradermally.

Preferably, the apparatus for administration
comprises an injection head provided with 1 to 10 noz-
zles, in particular from 4 to 6, preferably 5 or 6.

35 The apparatus for administration may have the
different characteristics given in the detailed
description. The preferred types of apparatus for
administration are those which reproduce the
administration conditions obtained with the Pigjet
apparatus.

The subject of the present invention is also the use of a plasmid combining a DNA sequence encoding an immunogen of a bovine pathogen and a promoter allowing the expression of this type of immunogen, for the preparation of a polynucleotide vaccine formula according to the different procedures described above, suitable for intradermal administration with an apparatus for liquid jet administration.

The subject of the invention is also a method of vaccination in which a polynucleotide vaccine formula, as described above, is administered by the intradermal route with the aid of an apparatus for liquid jet administration. The administration of the vaccine may be done by one or more deliveries of a determined volume of formula. Likewise, it is possible to envisage one or more vaccinations distributed over time.

The method of vaccination according to the invention may take into account the data mentioned above as regards in particular the apparatus for administration to be used.

The invention will now be described in greater detail with the aid of the nonlimiting embodiments of the invention with reference to the accompanying drawings in which:

- Figure 1 describes a plasmid comprising the BRSV virus G gene under the control of the hCMV promoter, for the vaccination of bovines against this virus.

- Figure 2 represents a graph comparing the efficacy of the vaccination against the BRSV virus by the intramuscular IM route (bovine 1349) and the intradermal ID route (bovines 1352 and 1353), with the days on the x-axis and the infectious titre on the y-axis.

Preparation of the BRSV synthetic G gene

The bovine respiratory syncytial virus is a Pneumovirus of the Paramyxovirus family. It is an enveloped virus which replicates in the cytoplasm and

has a single-stranded genomic RNA in negative orientation. The BRSV genome encodes two major transmembrane glycoproteins, the fusion protein F and the attachment protein G.

5 A synthetic conversion of the G gene has been prepared by removing from this gene or the potential splicing signals (G. Keil, Federal Research Centre for Virus Diseases of Animals, Friedrich Löffler Institute, D-17498, Insel Riems, Germany).

10 The region encoding the G gene has been determined by Lerch et al., (Journal of Virology, 1990, 64, 5559-5569). The coding region corresponds to 257 amino acids and to the characteristic of a type II transmembrane glycoprotein. It has an N-terminal cytoplasmic
15 domain of 40 amino acids followed by a transmembrane domain of 25 amino acids. The remainder, namely the 192 C-terminal amino acids, form the extracellular domain of the G protein. A DNA sequence has been synthesized having an open reading frame encoding exactly
20 the same 257 amino acids found by Lerch et al., but without the potential splicing signals. The reverse translation of the sequence of 257 amino acids into all the possible DNA sequences encoding such an amino acid sequence has been carried out. This was carried out
25 using the programme for reverse translation of a protein sequence RTRANS of PCGene by A. Bairoch., University of Geneva, Switzerland (IntelliGenetics Inc.). The potential splicing sites were determined using the "Signal" nucleic acid analysis programme.
30 This programme is based on the Staden weighted matrix method (1984, Nucleic Acids Research 12, 505-519). This programme identifies the potential donor splicing sites (intron/exon borders) and the potential acceptor splicing sites (exon/intron borders). With the aid of these
35 sequence data, it has been possible to mutate all the potential strong splicing signals without modifying the capacity for the protein. In particular, the GT dinucleotides which can form the 5' end of an intron

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and the AG dinucleotides which can form the 3' end of an intron were removed when possible.

To synthesize the suitable nucleotide sequence encoding G, oligonucleotides of about 100 residues covering the two strands of the complete sequence were synthesized with the aid of a DNA synthesizer (for example a Perkin Elmer/Applied Biosystems 381A DNA synthesizer; it is also possible to use commercially available oligonucleotides). The complementary oligonucleotides are hybridized so as to form a double-stranded fragment and cloned into prokaryotic vectors such as pUC18 or pUC19. Using appropriate enzymatic restriction sites, the cloned DNA fragments are linked together in the correct order using standard cloning procedures (Sambrook et al., Molecular Cloning : A laboratory Manual, 2nd edition, Cold Spring Harbor Laboratory, Cold Spring Harbor, New York 1989). The nucleotide sequence of the DNA fragment which results therefrom was determined with the aid of standard sequencing procedures (Sambrook et al.) to check that the sequence is correct.

Construction of the eukaryotic expression vector comprising the G gene behind the hCMV promoter.

To ensure its expression, the synthetic G gene was cloned into a vector. In this preliminary trial, a vector immediately available in the laboratory, namely the eukaryotic expression vector 175hCMV, was used. This plasmid vector contains two fragments derived from the BHV1 virus which flanked at the origin the E glycoprotein from the Dutch BHV1 strain called Lam (Van Engelenburg et al., 1994, Journal of General Virology 75, 2311-2318). The left-hand flanking fragment (Cterm gI) starts at the PstI site situated in the open reading frame of the gI glycoprotein and ends at the BstBI (or AsuII) site, 17 nucleotides upstream of the start of the open reading frame of the gE gene. This fragment is indicated by: Cterm gI. The right-hand flanking fragment starts at the EcoNI site situated at the level of the stop codon of the gE open reading frame and ends

at the level of the first SmaI site upstream in the terminal repeat (Tr) fragment. This fragment encodes the US9 gene. This fragment is indicated by : US9 and TR. These two fragments were cloned into the PstI site 5 and the EcoRI site (blunt end) of pUC18. Between the BstBI site and the EcoNI site, an AseI fragment (blunt end) of 720 bp containing the largest part of the human cytomegalovirus Immediate Early promoter (hCMV-P) was cloned with a polylinker region and ending with a poly-10 adenylation signal (Poly A). The synthetic G gene was cloned in the orientation indicated inside the SmaI site of this polylinker region. The plasmid obtained was called PR608. See Figure 1.

Control of the in vitro expression of G from the plasmid PR608:

A transient expression trial was carried out in order to test whether the plasmid PR608 can express the G protein. For this trial, 1.5 µg of purified DNA from the plasmid PR608 was transfected into a monolayer of 20 embryonic bovine tracheal cells (EBTr) in culture. These EBTr cells were cultured in Eagle's minimum essential medium with 10% foetal bovine serum (Integro) and antibiotics [125 IU of penicillin (Gist-Brocades), 125 µg of streptomycin (Biochemie), 37.5 IU of nystatin 25 (Sigma) and 37.5 µg of kanamycin (Sigma) per ml]. The transfection was carried out in accordance with the standard calcium phosphate precipitation method according to F.L. Graham and A.J. van der Eb (1973, Virology 52, 456-467). After transfection, the plasmid DNA is 30 transported into the nucleus of the transfected cells and the encoded proteins are expressed using the mechanism of the host cell. Normally, only 0.01% to 0.1% of the cells of the transfected monolayer will internalize the DNA and express the encoded genes.

Preparation of the DNA for the polynucleotide vaccination:

The DNA of the plasmid PR608 was prepared by adding 100 µl of a stock of E. coli K12 in glycerol, DH5alpha F- cells comprising the plasmid PR608, to

2 litres of LB medium, which is a standard medium for growing bacteria. This 2 litre culture is incubated at 37°C for 20 hours and the amplified cells are harvested using 250-ml flasks and an IEC Centra-8R centrifuge at 5 maximum speed. The DNA of the plasmid PR608 was isolated from the cells of the pellet following the standard alkaline lysis method of Birnboim and Doly as described by Sambrook et al., (1989, Molecular Cloning, a Press Laboratory Manual, 2nd Ed., Cold Spring Harbor 10 Laboratory Press). The plasmid DNA isolated was then dissolved in 20 ml of TE (10 mM Tris and 1 mM EDTA, pH 7.4) and subjected to electrophoresis to determine the DNA concentration and to assess the quality of DNA. From a normal 2 litre culture, it is possible to isolate 15 40 mg of plasmid; about 60% of the plasmid PR608 is found in the supercoiled state and about 30% in the relaxed circular state.

The plasmid preparation is stored at -20°C. Before application of the PR608 plasmid DNA, the DNA 20 solution is diluted to 0.5 mg/ml in 1x PBS and TE. This buffered DNA solution is pipetted into 10-ml flasks fitted to the Pigjet apparatus and stored at 4°C for use within 1 to 2 hours.

Pigjet apparatus for administration

25 The Pigjet-type, portable-type apparatus for administration comprises a casing provided with a handle, a chamber calibrated to 0.2 ml and a piston normally kept in the in position in the chamber by a spring integrally attached to the said piston.

30 The apparatus comprises, in addition, a head with 5 nozzles, intended to calibrate the jet, that is to say one head with 1 nozzle and a filtration device to avoid the injection of any possible impurities. The nozzles are slightly separated from each other.

35 The pressure of the jet at the outlet of the nozzle may be set at 100 bars for the Pigjet with 1 nozzle.

Brought about by appropriate means, the compression of the spring causes the movement of the

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piston and therefore the aspiration of the vaccine dose from a suitable reservoir or vial, attached to the casing.

Releasing the spring causes the return of the 5 piston and the discharge of the dose through the nozzle(s).

Vaccination and challenge trials:

4 calves free of specific pathogenic organisms 10 were obtained by Caesarean, were deprived of colostrum and were raised in isolation. The calves were vaccinated 6 times at 1-week intervals, from the age of 6 weeks. 2 animals were vaccinated by the intradermal route by means of the Pigjet with 1 nozzle (Endoscopic, Laons, France) and 2 animals were vaccinated 15 by the intramuscular route with a 25-gauge needle. The Pigjet is applied so that its head is in contact with the skin and perpendicular thereto, in order that the jet of vaccine has a direction orthogonal to the skin. Each vaccination consisted of 20 500 µg of plasmid DNA in 1 ml of PBS phosphate buffer. The intradermal vaccination consisted of 5 injections of 0.2 ml into the skin of the hind leg and the intramuscular vaccinations consisted of 1 injection into the gluteus muscle. The skin was shaved before 25 vaccination.

The antibody titres which appear in the following Table I were obtained:

- vaccination at weeks 0, 1, 2, 3, 4, 5
- challenge at week 6
- 30 - monitoring of the antibody titre at weeks 0 to 8

	0	1	2	3	4	5	6	7	8
Calf 1352	<5	<5	<5	80	640	1280	640	1280	>5120
Pigjet									
Calf 1453	<5	<5	<5	40	1280	640	640	640	*
Pigjet									
Calf 1349	<5	<5	<5	<5	<5	<5	<5	<5	<5
IM									
Calf 1350	<5	<5	<5	*					
IM									

a: These calves were sacrificed because of the appearance of major health problems unassociated with the vaccinations.

5 Following the DNA injections, the appearance of antibodies is observed at the end of 3 weeks in the animals vaccinated by the ID route and the appearance of high titres is observed from week 4, becoming a plateau.

10 The calves were then challenged with the infectious BRSV virus. The inoculation of the virus was carried out 6 weeks after the first vaccination by intranasal instillation of 1 ml of Odijk virus strain ($10^{3.8}$ TCID₅₀/ml) into each nostril.

15 To estimate the efficacy of the vaccination, the excretion of virus was monitored by the infectious titre TCID₅₀/ml up to 12 days after the infection, on nasopharyngeal swabs (sw) and in the lung washing fluid (Lav) (Figure 2).

20 It was possible to demonstrate that a plasmid encoding the BRSV G protein administered by the intra-dermal route by liquid jet protected against a virulent challenge with this virus. The intradermal vaccination by means of an apparatus for administration having a 25 discharge head with 1 hole rapidly induces high antibody titres against the G protein, which was not observed with the intramuscular vaccination. In addition, the infectious BRSV virus titres in the lung washing fluids and in the nasopharyngeal swabs were high in the 30 calves vaccinated by the intramuscular route and vir-

tually absent in the calves vaccinated by the intradermal route. The clinical signs were weak and were not markedly different between the animals.

A very good safety was also observed when the 5 Pigjet was used, this technique not in fact requiring a preliminary inflammation of the tissue to be induced as is the case with the gold particles.

In addition, what is remarkable is the obtaining 10 of protection with the G protein which is ordinarily not very immunogenic (P.L. Collins in : The Paramyxoviruses, 1991, Ed. D.W. Kingsbury, New York, Plenum Press) and the high antibody titre obtained after intradermal vaccination is comparable with that obtained after natural infection or vaccination with a 15 live vaccine tested in addition.

The invention also relates to the method for preparing the vaccine formulae, as given in this description.